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UNDERSTANDING COLOCATION REQUIREMENTS AND REFINING EXPECTATIONS ABOUT COMPUTER NETWORK USE: A FIELD STUDY OF ENGINEERING DESIGN ENVIRONMENTS

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Abstract

Expectations about the consequences of information technology frequently assume that computer networks will reduce the need for colocation. However, we do not clearly understand when these networks support collaboration among individuals who work in places geographically far apart and when they do not. This exploratory research seeks to understand work-process colocation requirements in engineering design environments. Among the important colocation requirements identified in the analysis conducted thus far are the inability to parse design tasks and design complexity defined as the number of variables or the interaction among variables that must be considered in the design process. Insights gained from this study may inform research focusing on business, medical, or other research settings.

1. RESEARCH OBJECTIVES

An assumption frequently made by both researchers who describe the strategic use of information technology and the emergence of virtual organizations (Davenport 1993; Lucas 1996; Scott Morton 1991) and technical developers who build software tools is that computer networks will reduce the need for colocation. Computer networks provide easy information exchange from one location to another and allow individuals to collaborate on work-related projects. However, we do not clearly understand when these networks support collaboration among individuals who work in places geographically far apart and when they do not (Kraut 1987). This research seeks to answer the question, "What are the characteristics of work processes that require individuals to be colocated regardless of computer network connectivity; that is, access to a network or network bandwidth?"

This exploratory research focuses on the colocation requirements of engineers who design complex products (e.g., semiconductors and automobiles). The sheer volume and complexity of information exchanged in engineering environments makes them rich and interesting settings for investigations of computer network use.

This research will be useful for software developers by providing a framework for understanding how engineering design processes may constrain the use of collaborative tools for individuals working across geographic distances. It will also contribute to the literature on emerging organizational forms by refining expectations about whether computer networks can be used to

[1]The author collected data for this research while a Visiting Lecturer at the University of Melbourne, Australia, in 1998.

support organizational forms intended to facilitate collaboration, across distances, among individuals involved in certain work processes, namely engineers working on the design of complex products.

2. THEORETICAL FOUNDATIONS

Colocation can be defined as the need to have co-workers in close proximity to complete a series of tasks involved in a work process, such as product design. Location requirements can be understood to fall along a continuum. At one end co-workers are in close proximity (e.g., in the same room) and at the other end co-workers are geographically distant (e.g., in a different country). In between are a range of other possibilities, such as co-workers in different rooms on the same floor, different floors but same building, different buildings but same site, different site but same city, and so on. This research focuses on work requirements that make in necessary for codesigners to be located in the same room or building or site.

Colocation means that the work process primarily requires face-to-face interaction and this requirement may vary by stages in the work process. Other media are not satisfactory or useful substitutes and thus cannot support interactions that might be conducted across great distances. Interestingly, media use research has not addressed the issue of variance of use across multistage work processes. Nevertheless, in product development, colocation may be important at earlier stages rather than at latter stages. Ancona and Caldwell (1990) have noted the importance of viewing product development as a multistage process and reported that new product teams progress from a creation phase to a development phase and finally a diffusion and ending phase. Adler (1995) has also studied different stages of the product development cycle and found that different coordination mechanisms are useful at different stages, which he identified as preproject, design (conceptual design and detail design), and manufacturing (pilot production and mature production).

Colocation may also vary by the interdependence among individuals whose combined contributions constitute a common work process. Thompson's (1967) set of three types of interdependence describe interactions among organizational units, but they could also describe the interactions among individuals working within a single (or multiple) organizational unit(s). The types are well known, but bear repeating to emphasize their hierarchical nature. Pooled interdependence exists when even though one unit may not interact with another; each unit makes a contribution to the whole. Sequential interdependence exists when the order of the contribution can be specified (i.e., a second unit cannot act until the contribution from the first unit is received). There is a pooled aspect to sequential interdependence, but the primary characteristic is the serial nature of the interactions between units. Reciprocal independence exists when each unit possesses a contingency for another; the outputs of each become the inputs for the others. While there are both pooled and sequential aspects to this type of interdependence, the primary characteristic here is reciprocity. Van de Ven, Delbecq and Koenig (1976) added a fourth type characterized by the simultaneity of multilateral interactions, such as the kind involved in therapy sessions or sports teams playing games. The fourth type is also hierarchical and adds the dimension of simultaneity. While these constructs have been criticized because they do not provide a way to measure degrees of interdependence (Victor and Blackburn 1987), they are useful for this exploratory investigation of colocation.

The interdependence among engineers designing complex products is reciprocal; however, depending upon the work process, they could also be characterized by simultaneous multilateral interactions. Since current network technology allows such interactions, this fourth type of interdependence need not require colocation.

Thompson does not address the issue of colocation directly. However, he does observe that in the case of reciprocal interdependence, coordination is achieved by mutual adjustment. And, to minimize coordination costs, "organizations seek to place reciprocally interdependent positions tangent to one another, in a common group which is (a) local and (b) conditionally autonomous" (Thompson 1978, p. 58). Greater mutual adjustments require more elaborate coordination mechanisms involving face-to-face interactions (Galbraith 1973), which require colocation.

However, not all design engineers appear to colocate. Kraut and Streeter (1995) found that among software engineers, the relationship between the use and value of electronic communication was greater than for other types of coordination techniques investigated, one of which was colocation. Recently Carmel (1999) described the success of 24-hour software development groups who work around the globe. On the other hand, mechanical engineers have had some difficulty in using computer networks and the Internet to support codesigners that are geographically far apart (Cutkowsky, Tenenbaum, and Glicksman 1996). An investigation of different, but similarly reciprocal, design processes should contribute to managerial expectations regarding colocation requirements and the role of computer networks in different design environments.

3. RESEARCH METHODOLOGY

In this exploratory field study, data were collected during 40 open-ended interviews. Most of the interviews were conducted among electrical and mechanical engineers. In addition, a small number of software engineers were also interviewed to learn how they have been able to conduct and coordinate development across geographically distant locations (Carmel 1999) (see Tables 1 and 2). The engineers interviewed had a range of experience and level of responsibility. They included individuals who had only worked as members of a design team as well as those with project or multiproject supervision or managerial responsibilities. Some of the engineers representing different disciplines worked for the same firm. (For simplicity, the terms engineer and designer are used interchangeably, although clearly not all designers are engineers and not all engineers are designers.)

Table 1. Number and Type of Designers Interviewed

Type of Engineer/Designer	Number Interviewed
Electrical Engineers	13
Mechanical Engineers	22
Software Engineers	5

Table 2. Number of Interviews by Firm

Type of Firm	Number Interviewed
Semiconductor Manufacturer	6
Telecommunications Manufacturer	2
Computer Manufacturers (2)	6
Satellite Manufacturer	2
Automobile Vendor (2)	7
Automobile Manufacturers (2)	9
Aircraft Vendor	8

Each open-ended interview included a series of questions that covered the following: the type of work performed by the designer, the nature and description of the products designed (currently and in the past), the stages of the design process, the nature of the interactions with other codesigners or key individuals during each of the stages, and descriptions or stories of "successful" and "unsuccessful" design collaboration that demonstrated the need for colocation or the ability to use network technology to support collaboration across geographical distance. These interviews ranged from 60 to 90 minutes in length.

Each interview was taped, transcribed, and then analyzed in two waves. First, following Glaser and Strauss (1967), the data was searched for themes related to the need for colocation in the different disciplines. Second, following Adler (1995), for each stage of the product design process, the nature of and motivation for the colocation requirement was identified if one existed. Only the preliminary results of the first wave of analysis are presented below.

The process of identifying the themes in the transcripts provided the framework for analyzing the data. Each transcript was reviewed two, three, and sometimes four times depending on the richness of the interviewee's articulation and insight. Analysis of the data paralleled the interviewing process. When a new elaboration or interpretation of a theme was found in a transcript, it was tested in subsequent interviews. Similarly, if a description was inconsistent with previous interviews, further clarification was requested in subsequent interviews. This process allowed an increase in the overall level of detail obtained.

4. DESIGN PROCESS COLOCATION REQUIREMENTS

Major themes that have emerged from the analysis conducted thus far include task parsability, the need for interdisciplinary expertise, feedback loops, task complexity, outcome specification, and organizational culture. The relative importance and the role of these factors represent colocation requirements that vary across different engineering disciplines and their respective design work processes. For example, the greater the interdisciplinary expertise required to complete the design work, the greater the need for colocation. Or, the more discretely the design can be parsed, the less the need for colocation. Overall, the colocation requirements for mechanical engineers and electrical engineers who design analog products appear greater than the colocation requirements for electrical engineers who design digital products whose development work shares some similarities with software engineers.

Products developed by mechanical engineers are difficult to parse, that is, to divide into a comprehensive set of component pieces that could then be assigned to and developed by different individuals working on a design. Moreover, because the products are three-dimensional and material in nature, there are important visual and tactile aspects of the design process. For this reason, rapid prototyping technologies have played a very important role in shortening product development times. The difficulty in parsing is evident in the following.

> If you need five people to work on [a component] at once, you are faced with a very challenging technical problem. The only way we know how to do it is to define a design in such a way that a given part is divided into…a virtual part that is made up of lots of pieces that may have no physical meaning. And, then someone somewhere has to take responsibility for putting it together and making sure that it all goes together and works and that those things where you agreed you really followed through on what you said. [Mechanical Engineer]

Another colocation requirement has to do with the interdisciplinary expertise that frequently must be called upon to inform design development and the time and communication constraints involved in doing so. Mechanical designers describe complexity in terms of the number of variables involved in any given product. These variables can be a set from a range of disciplines including geometry, physics, and materials science, as well as other engineering concerns including process specifications.

Electrical engineers developing analog products have somewhat similar colocation requirements as those of mechanical engineers. However, digital designers have very different requirements. Analog designers also describe complexity as the number of variables involved in any given design or product. On the other hand, digital designers describe complexity as the number of repetitions of similar events or components. The following captures this idea.

> There would be similarities in parsing a digital design and parsing an analog design, but there would be a level of complexity in the analog one that would be much larger and complicated. And, the complexity is related to the interaction of the different variables. Complexity for digital typically means more of the same. It's larger, it's bigger, you need more people, you need bigger computers, you need more time. Complexity for analog might mean you need a better analog engineer! [Analog Electrical Engineer]

Another important distinction is the measure of a successful design. A digital design is successful if it meets specifications, that is, if it performs functions that can be discretely stated. On the other hand, if an analog design meets specifications, that does not mean that the design is successful. Functional specifications for analog products cannot adequately represent what the design must do. Moreover, the level of detail in analog specifications is much greater compared to digital design and the designer must understand how the placement of the components will affect the outcome. The appropriate and correct placement requires an understanding of the interaction of a range of variables. Experienced designers understand the interaction between these variables. For the analog designer, as for the mechanical designer, the range of variables is great. But in the case of mechanical design, the colocation requirement is based on interdisciplinary expertise, whereas in the case of analog design it is based on the experience of analog engineers who understand the interactions of variables related to the placement of components in the design.

This very brief summary highlights some of the interesting explanations for colocation. In general, electrical engineers working on digital designs indicated that the capability to parse designs and work within the parameters of functional specifications are important attributes that allow designers to work at distant locations. On the other hand, mechanical designs are not easily parsed and often require interdisciplinary expertise including manufacturing process knowledge. And when manufacturing is done in a different company, the need to understand a different organizational culture is yet another colocation requirement. Analog designs require an understanding of the interaction of a range of variables that affect the placement of components in a given product. This means that designers must work with the design as a block, rather than separate parts, which contributes to the need for colocation.

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